



U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# Advisory Circular

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**Subject:** Geometry and Dimensional Considerations for Comparative Test and Analysis for Turbine Engine and Auxiliary Power Unit (APU) Replacement, Redesign, and Repaired Parts

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**Date:** XX/XX/XX

**Initiated by:** ANE-111

**AC No:** 33-Geometry  
(Draft)

## 1. Purpose.

**a.** To provide guidance on developing information for compliance findings of turbine engine/APU parts, referred to as “replacement parts,” produced under parts manufacturer approval (PMA), type certificate (TC), supplemental type certificate (STC), repair or alteration. Similarly, we will refer to aircraft turbine engines and APUs as “engines.” The resulting data may be used to support compliance to the airworthiness requirements of Title 14 of the Code of Federal Regulations (14 CFR) 21.303, part 33, part 43, and technical standard order (TSO) C77b. Airworthiness requirements are the type certification basis for the engine model that the replacement part will be installed on (same airworthiness requirements as §§ 21.303(a)(4), 21.303(b)(1), and 21.311). Also, § 21.1 defines the term “article” as a material, part, component, process, or appliance. Since this AC specifically applies to replacement parts, the term “part” is used instead of the term “article.”

**b.** We provide the guidance in this AC for applicants that use comparative techniques to reproduce the dimensional characteristics of type design parts. This AC does not address parts that are specifically designed to have dimensional differences from type design parts. We intend this guidance to support the use of comparative test and analysis for design and production approval projects.

**c.** This guidance helps applicants examine their reverse engineering methods for potential causes of dimensional differences. It also helps applicants establish adequate criteria for assessing dimensional similarity between the type design and the replacement parts, and develop sufficient validation procedures to avoid design errors that could lead to subsequent in-service safety problems, or product-level certification basis non-compliance.

## 2. Applicability.

**a.** This AC applies to anyone seeking PMA, TC, STC, or approval of repair(s) or alteration(s) of turbine engine/APU parts.

**This document does not represent final agency action on this matter and should not be viewed as a guarantee that any final action will follow in this or any other form.**

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**b.** This guidance is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. We will consider other methods of demonstrating compliance that an applicant may elect to present. We use terms such as “should,” “may,” and “must” only in ensuring applicability of this particular method of compliance when the acceptable method of compliance in this document is used. While these guidelines are not mandatory, they are derived from extensive FAA and industry experience in determining compliance with the relevant regulations. If we become aware of circumstances convincing us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional proof as the basis for finding compliance.

**c.** This material does not change, create any additional, authorize changes in, or permit deviations from existing regulatory requirements.

### **3. Related Documents.**

**a.** Advisory Circular 33-8, “*Guidance for Parts Manufacturer Approval of Turbine Engine and Auxiliary Power Unit Parts under Test and Computation*,” dated August 19, 2009.

(1) Explains the reverse engineering process for complex or critical engine parts requiring rigorous tests and analyses to show equivalency between the type design part and the proposed PMA part.

(2) Appendix 3 outlines the steps in a reverse engineering process for applicants to consider in a comprehensive test plan, and addresses the requisite for reverse engineering the dimensional characteristics of a type design part.

**b.** Advisory Circular 33-9, “*Developing Data for Major Repairs of Turbine Engine Parts*,” dated April 30, 2010.

### **4. Background.**

**a.** Generally accepted industry standards for establishing the dimensions and tolerances of engine parts don’t exist. Instead, the TC holder’s design is based on known product effects from variation in dimensional characteristics and manufacturing processes. This knowledge is not publically available. Further, it evolves with product-specific experience, and it is used to ensure parts are designed, produced, and managed in a way that preserves engine certification basis compliance throughout the engine’s lifecycle.

**b.** The Engine and Propeller Directorate has observed significant variation in the data that defines the dimensional properties of replacement parts for turbine engines. This variation is caused by inconsistencies in the applicant’s understanding of the original part design and how it functions in the engine. In some cases, the applicant’s reverse engineering procedures resulted in dimensional differences in a replacement part that influenced the engine environment enough to compromise the structural integrity of other parts in the engine. These differences, and their

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effects, were not identified during the design approval process, but were later found during an engine failure investigation after the part entered service.

c. Dimensional differences in replacement parts have also resulted in product configurations that are no longer compliant with their certification basis and can no longer be managed using the original manufacturer's Instructions for Continued Airworthiness (ICA). The sensitivity of engine systems to dimensional differences in replacement parts is not necessarily observable from the data acquired during the part-to-part comparative assessments. Depending on the nature of the part and the engine systems that are affected by the part, data showing these sensitivities may only be available through product testing.

d. Reverse engineering methods do not typically produce a design with the exact same dimensional properties as a type design part. This is because reverse engineering methods vary considerably in measurement techniques, how measurement data is interpreted and combined, and in the dimensioning systems; all of which affect the dimensional similarity between the type design and replacement parts. Conclusions regarding dimensional similarity are only valid when a single method is used to develop the dimensional properties of the type design and replacement parts.

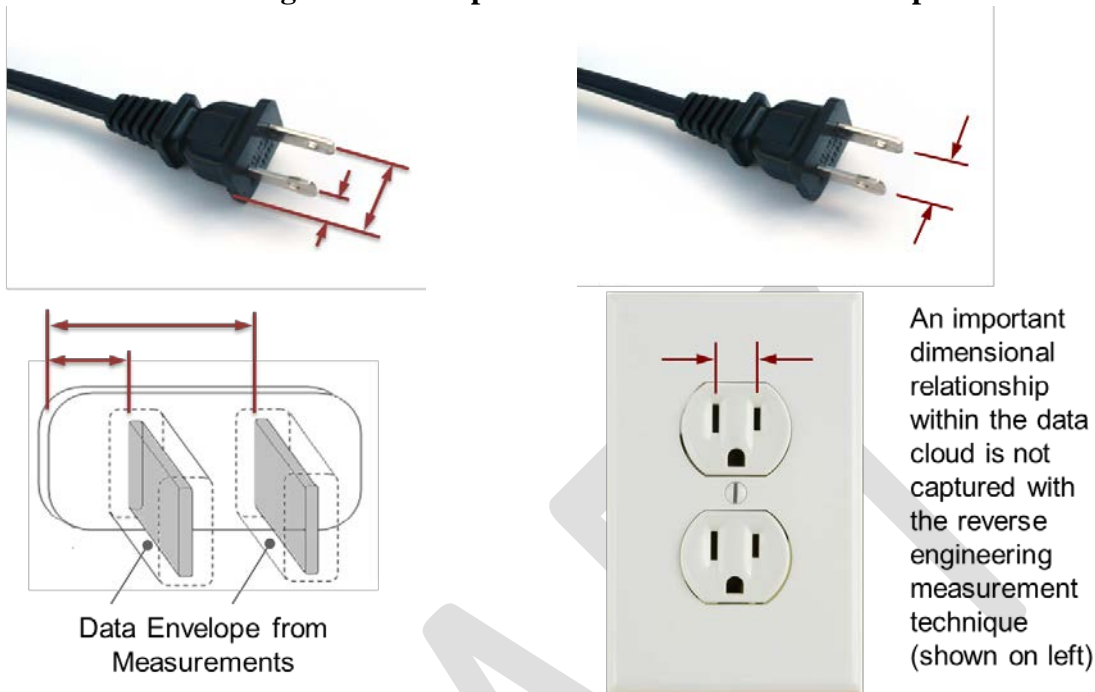
e. Since it is not likely that aftermarket applicants will duplicate the OEM's methods for measuring and dimensioning the type design part, dimensional differences between the two parts can exist. Therefore, to safeguard the type design functional properties within the replacement part, and to safeguard the capabilities of interfacing parts and higher level assemblies, functional assessments will be necessary to ensure the dimensional characteristics are equivalent. Depending on the complexity of the type design part, the functional assessments could require both test and supplemental analytical data, for example, to account for the effects of the full range of reverse engineered dimensional variation on the part function.

**5. Guidance.** This AC shows several considerations that can help applicants develop the dimensional characteristics for replacement parts and enhance their showing of similarity. Due to the wide range of reverse engineering techniques and manufacturing processes used by the industry, other causes of dimensional variation that are not mentioned in this AC may exist, so the applicant should develop validation procedures that account for the possibility of these and all other potential sources of dimensional variability.

**a. Geometric Relationships.**

(1) Some reverse engineering techniques generate a cloud of data from cumulative dimensional scans of multiple original parts to determine the dimensional characteristics for their replacement part. However, assuming the replacement part shape can exist anywhere within the maximum and minimum dimensional limits derived from measuring multiple original parts may introduce unintended error. For example, design requirements might exist for the original part that maintains trends, positional dependencies, and relationships among part features within a data cloud. These relationships are not always obvious. Figure 1 provides an example showing the importance of understanding the part's functional design.

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**Figure 1. Example of a Dimensional Relationship**

(2) Similarly, if a surface tolerance was reverse engineered using only a maximum and minimum material condition without controlling surface transitions within the material envelope, the reverse engineered surface may allow trends and step changes that are not present in the original design. If the reverse engineered dimensional characteristics allow these anomalies to exist in the surface of the replacement part, but they are not observed in the surface of the original parts, then the criteria that established the reverse engineered surface is not complete.

(3) A fundamental understanding of how the part functions in the engine is necessary to preserve the dimensional relationships intended by the original engine manufacturer. These relationships can influence the functional properties of the part and the integrity of associated critical parts. Therefore, reverse engineering criteria and measurement techniques that establish geometric relationships should reflect an understanding of the functional requirements of the part, and not be based solely on a normal distribution of the total variation within a cloud of data.

#### **b. Datum Selection and Reference Dimensions.**

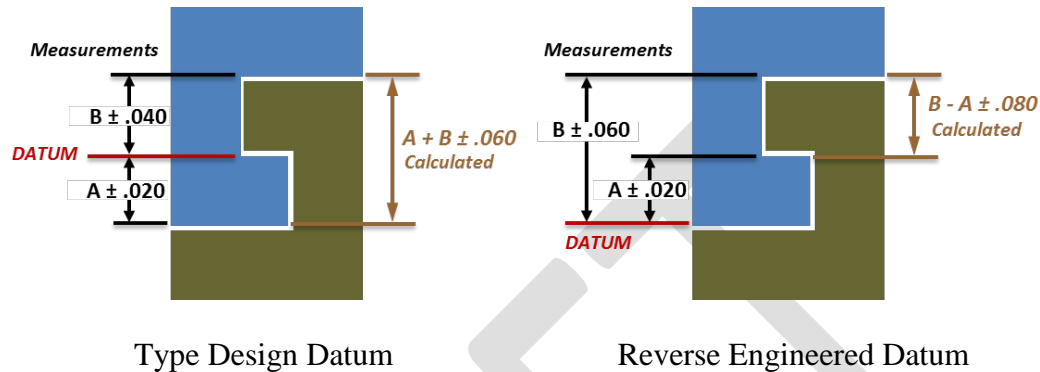
(1) Datum selections influence the dimensional characteristics of a part. Datums are typically established based on how the part functions in the engine. Datums locate features of the part relative to other features, and the part relative to other parts in the engine. Datums also ensure the part fits in the assembly and functions properly in the engine. Proper datum selection will take into account considerations, such as fit with adjacent hardware, function, and the state of the part while it is in operation.

(2) Figure 2 shows how the selection of a datum can affect the interface between adjacent hardware. The figure on the left represents the type design and the figure on the right

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represents a reverse engineering technique that places the datum in a location that could result in an interference fit with adjacent hardware.

**Figure 2. Example of How Datum Selection Can Affect the Interface Between Parts**



(3) Reference dimensions are theoretical distances that locate features constrained by tolerances elsewhere on the feature. They can also be calculated from a stack-up of many other dimensions, and placed on the drawing solely for convenience. The accuracy of a feature defined, in part, by a reference dimension can affect contours and transition of features that support the proper function of the part and its interface with other parts. Paragraph 5f of this AC provides an example of a transition feature.

(4) An improper datum selection or inaccurate reference dimension can adversely affect safety. For example, dimensional differences, or excessive variation in key features at the interface with adjacent critical hardware, can affect the applicability of the TC holder's ICA for the critical part.

(5) Another example of a reverse engineering method that will not necessarily preserve the functional design is the use of pin gages to establish datums. Although pin gages are used by the TC holder to qualify used or repaired type design parts, pin gages do not provide enough information to reverse engineer a part. A pin gage contacts a particular location on several surfaces and averages the variation of the surfaces touched by the gage. This technique does not provide any insight into tolerances, tolerance controls, datums, reference dimensions, or coordinate systems that were used to define the dimensional attributes of the individual surfaces touched by the pin gage on the original part. Depending on how the applicant uses these measurement data for reverse engineering, this technique can create a different datum system for the replacement part that decouples the original and replacement part dimensional attributes.

(6) Measuring the dimensional variation of a type design part using datums created for replacement parts can make the type design part appear to have more variation than that of the replacement part. For example, if replacement part datums are used to align the replacement and type design parts for a dimensional comparison, and the datums for the replacement part are established using the external surfaces of type design parts, the variation in type design parts will appear to be greater than it really is. In this case, the replacement parts will exhibit less variation

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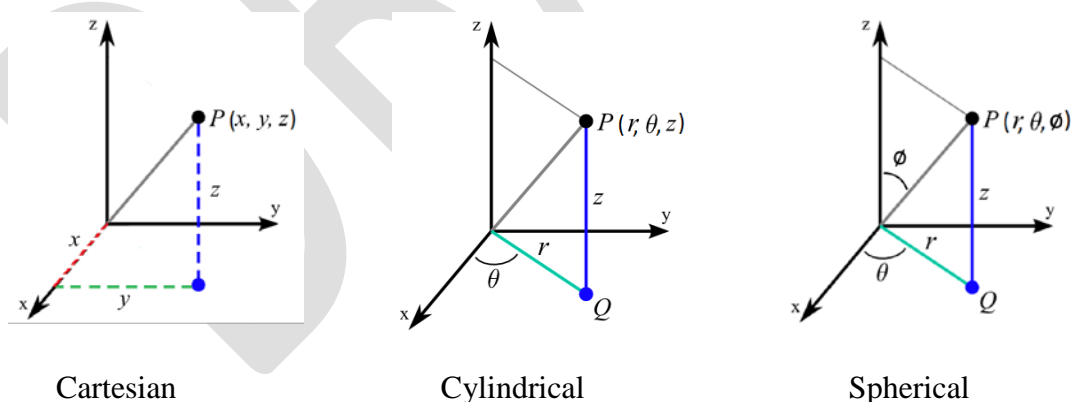
than they would if they were compared using the datums that were developed for the type design part, but they will in fact have more variation.

(7) Depending on the part, increasing the dimensional variation beyond the variation measured in type design parts can adversely affect the functional design of the part and the integrity of interfacing hardware. For example, more variation in highly stressed turbine blade dovetails can further increase the stress at the disk and blade contact surfaces, resulting in fracture of the disk post from accelerated wear or fatigue. Also, more variation in adjoining rabbets at the interface between combustors and casings can increase wear and reduce the maintenance interval; more variation in airfoil contours and load bearing shafts can have a substantial effect on their dynamic properties causing excessive flexure, stresses, and failure from fatigue.

(8) The selection of datums and reference dimensions should be clearly portrayed in the data package and supported by evidence showing that the selections safeguard the part function and its interface with adjacent and critical parts, thereby preserving engine airworthiness.

**c. Establishing Coordinate Systems.** Applicants can use various coordinate systems to define a part dimensionally. Examples of coordinate systems are Cartesian, Polar, Cylindrical, and Spherical systems. Choose the coordinate system appropriate for the part shape, function, and features that require dimensional control and its interface with the next higher assembly. Figure 3 shows some examples of coordinate systems.

**Figure 3. Examples of Coordinate Systems**



**d. Non-Uniform Tolerances.**

(1) Measurements taken from type design parts should be sufficient in precision and density to detect the presence of non-uniform tolerances. Non-uniform tolerances in a part may indicate the presence of unique dimensional controls that support the proper function of the engine throughout the type certificated operating range. They may also indicate the existence of local areas on a part where geometric variation has little or no effect on product compliance. Reverse engineering methods should be able to distinguish when non-uniform tolerances are

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implemented for functional purposes, and when they are feasible because the engine is more tolerant to the larger variation.

(2) Some reverse engineering processes assume the largest tolerance, measured from a particular feature on an original part, applies evenly across the feature. This technique is suitable if the maximum tolerance is observed over the entire feature, or if the non-uniformity is an artifact of how the original part is seated in a fixture. However, non-uniform tolerances in a type design part may occur for various reasons.

(3) In some cases, original parts build in variable tolerances to accommodate the need for certain dynamic properties during specific engine operating conditions. In other cases, non-uniform tolerances can result from hand blending procedures that are allowed in specific areas of the part, such as the trailing edge of some airfoil designs. In both cases, the largest measured variation in the type design part should not be automatically applied to the entire area of the replacement part, because the resulting variation in the replacement part will exceed the range of variation intended for the original part. Depending on the nature of the part and complexity of the engine systems that are affected by the part, the effects of increased dimensional variation on product compliance can be difficult to assess without product testing.

**e. Combining Measured Variation.**

(1) Applicants define the dimensional variation of a single feature on a part using multiple tolerance controls. For example, a surface could have a tolerance for position relative to a datum, and another for profile. Each tolerance in the dimensional stack might be acquired separately by taking the measurements from the type design part while it is in a free state, independent of a fixed datum. The separate measurements are then combined to establish the total variation of the feature.

(2) The applicant's reverse engineering techniques will determine how to combine the measurements, as numerous ways are available to combine them, and the various combinations can result in a different dimensional stack-up.

(3) For some design features, small variations in geometry can affect functional properties, such as operating stresses, fatigue, vibration, wear, and failure modes. Therefore, applicants must ensure that their reverse engineering techniques combine their measured tolerances in such a way that preserves the total variation intended by the original part designers.

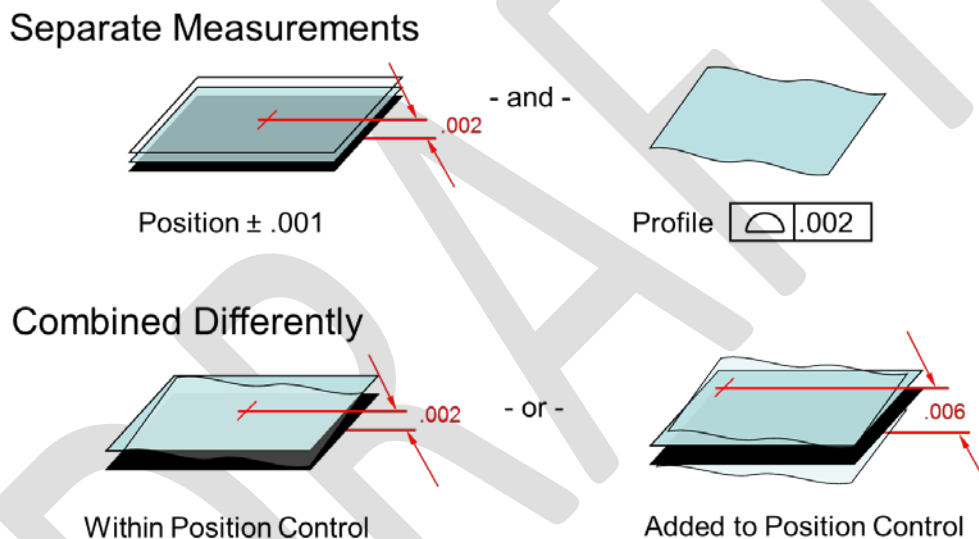
(4) An example of a functional requirement is maintaining contact stresses below a certain stress threshold. The original design might achieve this requirement by limiting the dimensional variation in a feature at the interface with another part. The interfacing feature may have several tolerance controls that are stacked in a way that minimizes the total dimensional variation. Reverse engineering techniques can stack tolerances in various ways, and, therefore, measurements taken from original parts alone will not necessarily guarantee preserving the range of stress in the replacement part.

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(5) If the type design combines tolerances to minimize the total variation in a feature and the reverse engineered design combines tolerances to maximize the total variation, the wear characteristics and stress at the interfacing features of both parts could be greater than those experienced by the type design. If replacement part manufacturers do not have insight to these dimensional characteristics of the original design, they must adjust their methods appropriately. For example, they should implement validation methods to ensure the reverse engineering techniques result in a replacement part with the same dimensional variation.

(6) Figure 4 shows two measurements taken separately and two combined in different ways. An understanding of the functional design is necessary to determine which method duplicates the type design dimensional properties.

**Figure 4. Combining Separate Measurements and Functional Design**



(7) Similarly, when assessing dimensional differences between replacement parts and the original part, combining the nominal shape with the variation around the nominal shape for each part under comparison is important. Comparing the minimum and maximum contours around the nominal shape will show the extent of physical differences between the replacement part and the original part.

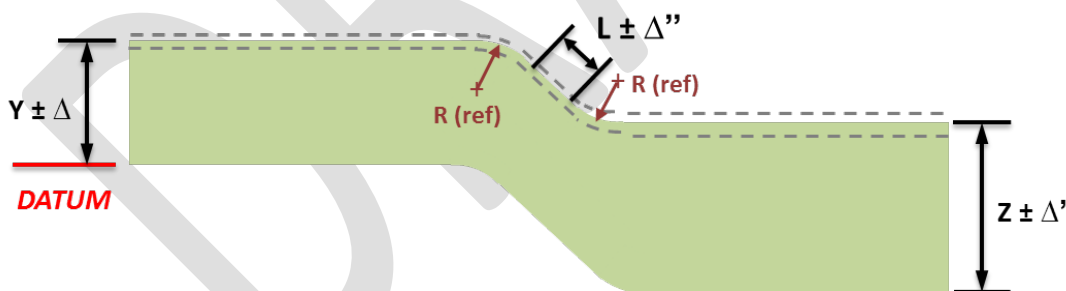
(8) The extremes of the physical differences from the type design part must be reconciled to the applicable airworthiness requirements. Assessing the parts separately for differences in nominal shapes and variation, without including the total variation for each part, will not show if the replacement part geometry is within the original part geometry, or if there are dimensional differences in the replacement part. Also, there could be other dimensional controls within the contour that applicants must compare to determine the extent of physical differences between the parts, like non-uniform tolerances and rate of dimensional changes on a surface. Figure 5 shows an example of differences when considering total variation around nominal shapes.



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**Figure 5. Example Showing Differences in Total Variation****f. Transition Features.**

(1) Corners, fillet radii, and transition radii contribute to the functional design of the original part, interfacing parts, and higher level assemblies. The dimensional variation in transition features may not be directly controlled, but are an outcome of other dimensions and tolerances for adjacent features, which may or may not be load-bearing. Figure 6 shows an example of how the dimension of a feature can fall out of the manufacturing process. If the feature is important to the functional requirements of the part, then the dimensional controls will need to be developed so the resulting dimension is within the range intended by the designers. Differences in transition features have the potential for concentrating stresses, accelerating wear, and initiating fatigue cracks well within the operating mechanical and thermal design loads. The reverse engineering process must be capable of identifying the dimensional characteristics for transition features that are essential for preserving stresses and interfaces with adjacent parts.

**Figure 6. Dimension “L” is an Outcome of Other Dimensional Controls**

(2) Reverse engineered transitions or blends must not introduce new features that do not exist in the original part. For example, contact surfaces with critical hardware are designed to preclude raised features or sharp contact edges at the interface. Therefore, the validation procedures for the replacement part must include an assessment of the full variation in transition features allowed in replacement parts.

**g. 3D to 2D Translation.**

(1) Some reverse engineering methods involve equipment and analytical techniques that develop a three dimensional model from measurements taken from multiple type design

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parts. A three dimensional model is created and then converted to a two dimensional drawing that defines the geometry and dimensional characteristics of the replacement part. The two dimensional drawing dimensioning system incorporates datums, reference dimensions, tolerances, and geometric controls that have an influence on the amount of variation in individual features, and in the relative position of individual features.

(2) The replacement part manufacturer develops their own dimensioning system for their part. Since they do not have the TC holder's drawing, their drawing could implement different dimensional criteria that increases the dimensional variation in replacement parts beyond the extent intended by the original part designers. Dimensional differences can adversely affect the functional design of the part and have undesired effects on interfacing parts. Therefore, applicants should not base the replacement part drawing definition solely on goals to facilitate the replacement part manufacturing and inspection processes. Although there may be a need to develop drawings that relate to in-process manufacturing requirements for the part, the reverse engineered finished-part drawing dimensioning system must be developed based on an understanding of the part's various functional requirements, and verified by assessments that account for potential sources of variation, some of which are mentioned in this AC.

#### **h. Precision and Accuracy.**

(1) Precision is the number of digits used to define a value. Accuracy is the closeness of the measurements to its actual value. The required precision for the measurement should be appropriate for the feature being measured. The precision to which a feature is measured will affect the resulting variation in the part. Certain features will have very little variation, compared to the rest of the part, for various reasons. Maintaining the dimensional variation to within a small range might be necessary to keep mechanical stresses below a design threshold, preserve the desired aeromechanical properties, control the location of the part within an assembly, or minimize wear between interfacing parts. Reproducing variations ensures these properties, as well as other functional properties, are preserved in the replacement part.

(2) Normally, reverse engineered measurement precision is determined by increasing the measurement precision until a threshold is reached where the measurements are consistent and no longer change with higher precision measurements. Measurement techniques that are less precise than the precision to which the type design part was manufactured will mask the actual variation, will increase the variation in the replacement part, and can fail to reveal features that are in the type design.

(3) Using industry-standard manufacturing processes alone to establish finished-part tolerances can affect the dimensional accuracy of the replacement part when the type design part has inspection criteria that are tighter than the standard manufacturing process capability. Similarly, reverse engineering techniques that offset nominal shapes, or expand the tolerance range observed in type design parts to match manufacturing process capabilities, can affect the dimensional accuracy of the replacement part. Selecting tolerances based on assumptions on common design practices among engine manufacturers and engine models is another way of introducing substantial changes to the replacement part. Reverse engineering processes that use

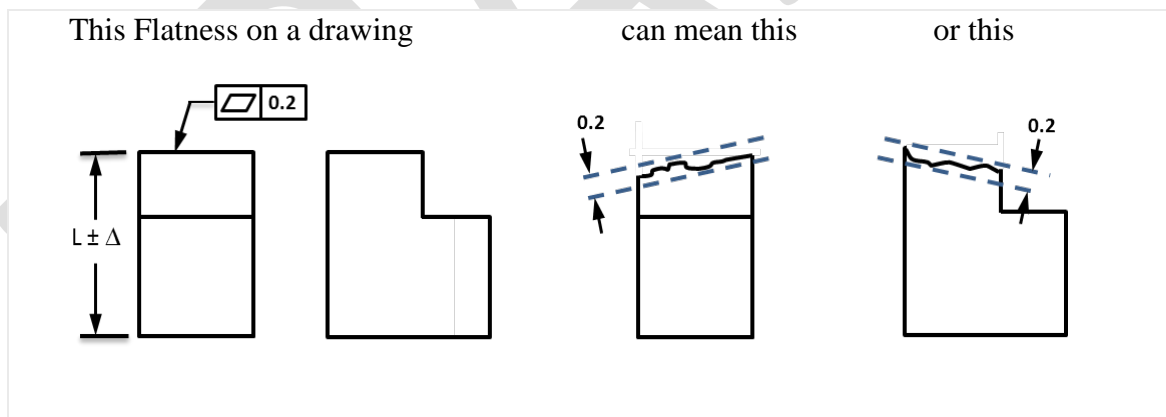
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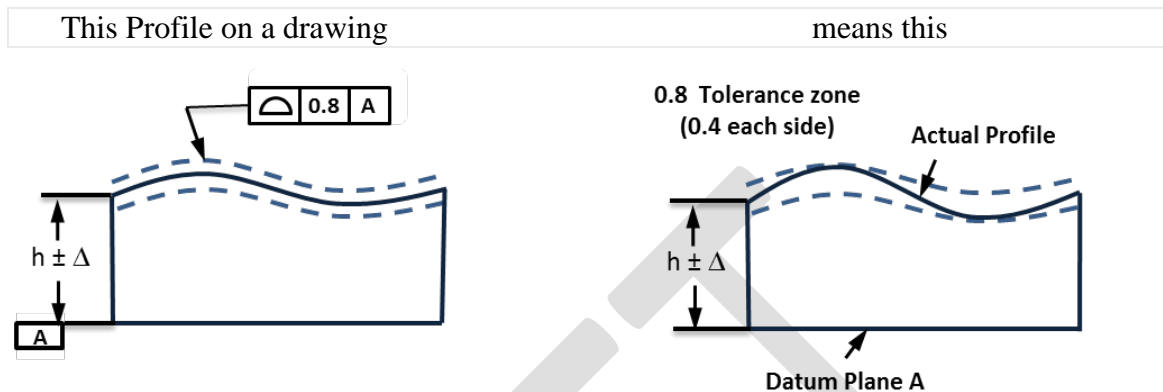
techniques such as these, involve assumptions that can introduce substantial changes to the replacement part and could require validation methods that are comparable to an STC.

#### i. Choice of Tolerance Control.

(1) There are a number of options available for characterizing the dimensional variation of a part, which could affect the functional properties of the replacement part. For example, if the type design part defines the dimensional variation of a load-bearing surface by tolerances that control the contour and the distance relative to a datum, and the reverse engineered surface is characterized only by a contour, then the position of the load-bearing surface relative to the datum can vary as much as the manufacturing process allows. This can cause loads to be concentrated in a feature or redistributed among adjacent features, resulting in stresses or wear that exceeds the maximum limits intended by the original part designers. Similarly, using a flatness requirement for a surface, instead of a profile, to control the variation in a load-bearing surface could change the load intensity, distribution, and wear properties at an assembly interface. Profile checks all the measured points back to a datum (or datums), and flatness is independent of alignment and gives the distance between two parallel, imaginary planes, which will contain all of the points. Figures 7 and 8 illustrate the differences between the flatness and profile tolerance controls.

**Figure 7. Flatness Tolerance Control**



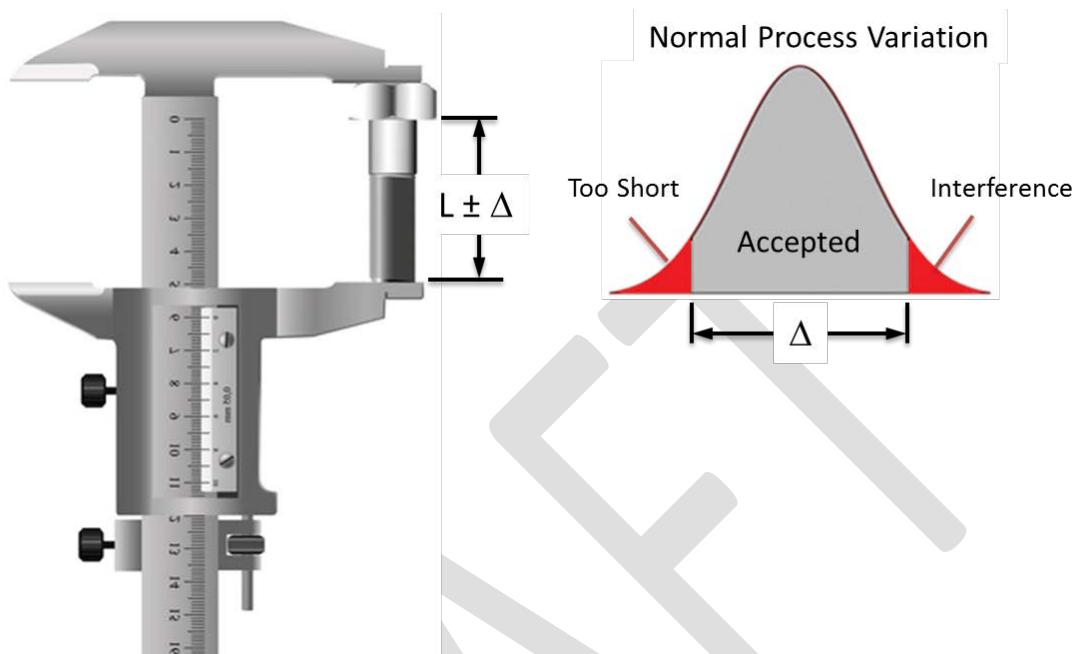
**Figure 8. Profile Tolerance Control**

(2) Differences in tolerance controls that affect surface-to-surface transition radii can also result in stress concentrations from sharp contact features and non-uniform surfaces. Sometimes, these stress concentrations are only apparent when assessing the maximum or minimum material condition of the interfacing parts. Concentricity, circularity, and run-out are also examples of tolerance controls that can affect the dimensional similarity and functional design of cylindrically shaped parts. Therefore, applicants should carefully examine the part and its function to determine the appropriate dimensional controls.

#### **j. Statistical Dimensioning.**

(1) Some reverse engineering techniques propose to fit a statistical curve to data obtained from measurements taken from a sample of type design parts. This approach expands the range of dimensional variation in the replacement part beyond the measurements taken from the original parts. However, to show that a normal distribution accurately describes the full range of dimensional variation in a type design part, many more type design samples are necessary for this approach than is typically used for a replacement part project.

(2) Measurement data may exhibit a good fit with a particular statistical distribution, but a manufacturer's inspection criteria will sometimes reject parts outside a small range of the distribution to preserve an important design characteristic, like tolerance stacks with critical mating parts, dynamic properties, and maximum allowable moment weight. Figure 9 shows an example of how inspection limits can be used to screen parts to ensure the dimensional attributes are appropriate for the higher level assembly.

**Figure 9. Example of a Truncated Process Distribution**

(3) Inspection limits might restrict or bias dimensional properties of a part to ensure all parts in an assembly can be assembled to enhance performance, to minimize wear, or to preserve other functional properties. Consequently, statistical methods alone are not a sufficient means for establishing the extent of dimensional variation allowed in a part or for supporting proposals to expand the range of variation observed in the type design parts. Also, part-to-part bench tests usually do not include replacement parts that are made to the extent of their reverse engineered dimensional limits, or any interfacing type design hardware made to the extent of its dimensional limits. Bench tests may not extract all the information necessary to identify dimensional differences that could affect fit and function. Staying within the measurements taken from type design parts will ensure any special inspection criteria applied by the TC holder are captured in the replacement part design.

(4) If the applicant uses statistical methods to smooth tolerances across a feature, care must be taken to ensure a sufficient number of type design samples are used, and the measurement density and precision is adequate to account for the possibility of non-uniform, restricted or biased tolerances, which might be necessary for proper function throughout the certificated engine operating range.

#### **k. Surface Roughness.**

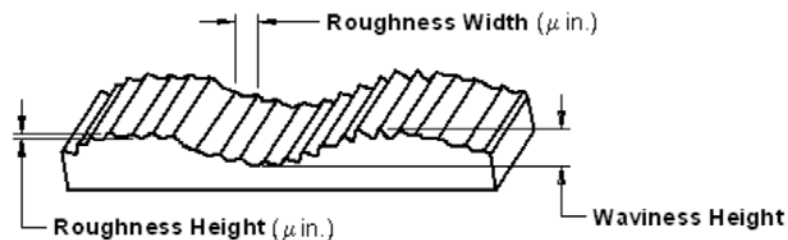
(1) Surface roughness is a feature that can affect various aspects of the functional design of a part, such as fatigue, wear, and performance. For example, airfoil surface roughness, or smoothness, affects both fatigue properties and engine performance. The effect of differences

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in airfoil surface roughness on fatigue might be measurable with the proper comparative bench test, but the effect on engine performance can be difficult to quantify without engine testing.

(2) Many techniques are available for measuring surface roughness. The method used to quantify surface roughness for a specific part must be adequate to ensure the roughness in the replacement part is equal to that of the original part. Figure 10 shows various features that contribute to surface roughness. The actual measurement will depend on how applicants measure and analyze these parameters in calculating surface roughness.

**Figure 10. Various Parametric Features to Surface Roughness**



(3) If the type design part surface is treated by a process that produces a compressive layer, then the roughness is a result of the surface treatment. Care must be taken to reproduce the dimensional aspects of the compressive layer and surface roughness in the replacement part. Processes for replacement parts that remove material from treated surfaces to reduce roughness, with the intent of improving component performance, can compromise the benefit of the surface treatment to fatigue and durability. This surface treatment benefit may be required to achieve the certificated product performance.

#### **I. Influence on Critical Parts.**

(1) Some parts interact with critical parts to varying degrees. These parts can influence a critical part's ability to meet its prescribed integrity requirements. For example, they may interfere with a critical part's ability to satisfy requirements found in §§ 33.27, 33.70, 33.76, and 33.94. Interactions occur at interfaces where the parts make physical contact, and at interfaces that do not touch but provide the boundary conditions to maintain the operating environment within certain limits. Measurements taken from type design parts alone might not provide enough information to duplicate the interface such that the interaction with critical parts is the same. For example, the dimensioning system for the replacement part affects the amount of variation in features that interface with critical parts. If the dimensioning techniques allow for more variation in the replacement part, then differences could exist in the replacement part. The effect of dimensional differences in parts that interact with critical parts is very difficult to assess without substantial type design and manufacturing details.

(2) You may generally assume dimensional differences exist in replacement parts when reverse engineering techniques are developed without type design and production details. This AC shows some potential causes for dimensional differences and increased variation in replacement parts. To support the approval of replacement parts that interact with critical parts,

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applicants should consider the potential for differences in the compliance data. If differences can exist, duplication will likely require detailed knowledge of the interfacing parts and the conditions that must be maintained at the interface.

(3) If the critical part is life limited, the applicant will need a method for assessing the effects of the differences on the life of the part. Normally, the information required for a lifing method is only available through product testing. Therefore, applicants must take care to ensure that parts having an influence on critical parts are dimensioned within the measurements taken from type design parts, and that the potential for differences is addressed. If you have insufficient information to conclude the parts are dimensionally equivalent, your validation procedure would likely require a direct showing of compliance to the affected airworthiness requirements.

**m. Minimum and Maximum Material.**

(1) The replacement part design encompasses the geometry of the part manufactured to its dimensional limits. The minimum and maximum material part corresponds to the minimum and maximum dimensional tolerances. These limits include the cumulative effect of any differences, or offsets, in the reverse engineered nominal shape and tolerances.

(2) The replacement part assessments that show the replacement part is functionally equal to the type design part must account for the replacement part properties when the part is manufactured to its reverse engineered minimum and maximum material limits. Normally, applicants use samples of type design parts to establish the dimensional limits for the replacement part, and they manufacture replacement part samples to be within these limits. However, the reverse engineering processes that establish the dimensional characteristics of the replacement part (datum selection, combining measured variation, choice of tolerance controls, etc.) affect these limits.

(3) Since replacement part test samples are not usually made to their material extremes, the compliance showing might require additional assessments that extrapolate the test data, to include the extremes of the drawing limits to ensure similarity in functional properties that are sensitive to variation in geometry. This consideration becomes increasingly important when the material condition affects the interface with a critical part.

(4) Exceeding the dimensional limits of a type design part could expand the scope and expense of the project significantly. For example, a maximum material replacement blade must not exceed the maximum moment weight measured from a sample of type design blades. However, if the replacement parts used for the moment weight comparison meet this certification criterion, but are all biased toward the minimum material condition, then replacement blades made to the maximum material condition after certification could exceed maximum moment weight. Applicants could use an analysis to ensure the moment weight of a maximum material replacement blade is within the maximum measured moment weight of the type design blade at the time of certification.

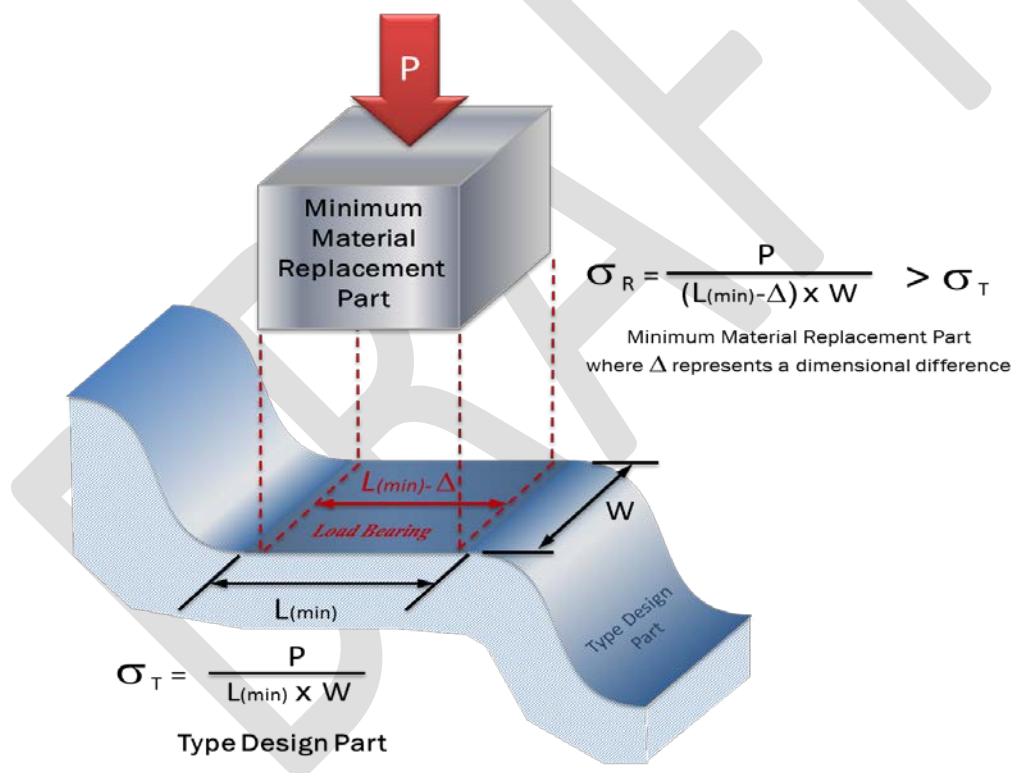
(5) Applicants should examine the dimensional characteristics of the minimum material replacement part. The minimum material condition can influence stress in a part in

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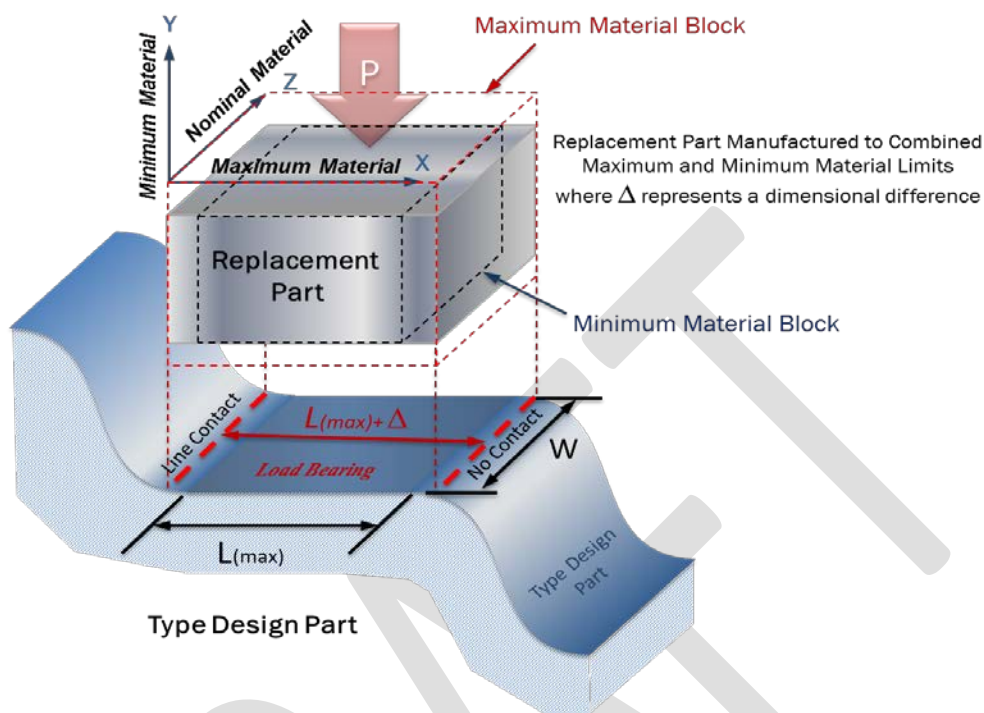
various ways. For example, the stress at load-bearing surfaces under compressive or tensile loads can be affected if the minimum material condition causes the load-bearing area to drop below the minimum type design area. Similarly, high stresses can result when the minimum material condition increases a stress concentration, or results in sharp transition features that do not exist in type design parts. Sharp transition features can result when a sharp contact surface impinges on the adjacent hardware at a location that is not supposed to be in contact, resulting in improper seating between the two parts and premature wear or fatigue failure.

(6) Figures 11 and 12 illustrate how dimensional differences between a replacement part and a type design part can lead to functional differences and latent engine effects when the replacement part is manufactured to its reverse engineered dimensional limits. The issues shown in these figures may not be detectable from data acquired using methods based in test and computation and a sample of replacement parts.

**Figure 11. Minimum Material Replacement Part Resulting in a Higher Contact Stress**





**Figure 12. Mixed Material Conditions Resulting in Line Contact and Free Surfaces****n. Selective Assembly.**

(1) It is important to recognize when the TC holder separates type design parts into groups for installation into specific product models based on where the dimensional properties fall in the range of manufacturing process variation. A single part number could be eligible for installation in a variety of engine models with different ratings, operating limits, and missions, but only some of the parts are considered eligible for installation in products with the highest operating severity.

(2) Selecting the most desirable part for a specific engine model can include criteria that identify dimensional attributes that are either biased to one side of a tolerance band, or are closest to nominal dimensions. For example, parts manufactured closest to the nominal shape might be selected for the most severe operating conditions, if the nominal drawing dimensions represent the ideal design, while the remaining parts are used in less severe environments. Also, TC holders may hand-select parts and group them together, based on their dimensional properties to preserve key characteristics in a higher level assembly. This criterion can effectively restrict certain parts from being mixed at random, or distribute parts for assembly into a family of product models. Examples of the kind of parts that could be managed by selective assembly are interfacing gears, piston and sleeve combinations, parts that assemble with interference fits, and parts where average moment weight is maintained below a specified limit to preserve the integrity of interfacing life-limited parts. Higher level assembly drawings, which have this

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dimensional criterion for selective assembly, would not necessarily be discovered by examining individual type design parts.

(3) When an applicant proposes to expand the engine model applicability for a specific replacement part number to include product models with different performance ratings, it is appropriate to be cognizant of the potential for selective installation, and to take the required measurements to determine if the TC holder is using this method in their assembly process. Although this practice is not wide-spread, it is an effective way for TC holders to ensure their engine configurations have the required durability to meet their ICA.

**o. Coatings.**

(1) Some type design parts are coated, so the coating becomes part of the reverse engineered design for a replacement part. In some cases, the coating is duplicated as part of the overall effort to copy the type design part. In other cases, new coatings are developed as part of a non-type design repair and added to the type design part to improve resistance to environmental effects, such as erosion. Repairs might also expand the coating area beyond the area covered by the type design repair.

(2) Parts that operate in the gas path are highly customized designs developed to satisfy product requirements. Airfoil contours, tolerances, contact surfaces, coating material, and aeromechanical properties are examples of design features that can be affected by coatings. Coating materials and dimensional requirements are developed by the TC holder and evolve over the product lifecycle. Dimensional differences in coatings can have a substantial influence on product compliance. Coatings developed for replacement parts and non-type design repairs present opportunities for dimensional differences.

(3) The dimensional comparison of replacement parts and type design parts must evaluate the replacement part for differences in coatings and coated surfaces that can influence product performance and reliability, such as coating thickness, coating taper between the contact surfaces of two mating parts, transition geometry from coated surfaces to non-coated surfaces, and airfoil leading edge contours. If a type design part is being copied in parallel with a type design coating, the dimensional comparison must include the extent to which the replacement part can be manufactured with the reverse engineered coating. Paragraph 5e of this AC provides additional information on how to assess replacement and type design parts to the extent of dimensional differences.

(4) Applicants must evaluate the effects of the full extent of dimensional differences in replacement parts using suitable methods, and with the accuracy and fidelity that is consistent with the regulatory requirements that establish the airworthiness of the product. This is because some requirements involve an engine demonstration test, and the compliance methods used by the replacement part applicant cannot introduce uncertainty to the results obtained by the demonstration tests.

(5) Validating dimensional differences in coating thickness and coated areas for some parts, depending on its functional requirements and criticality, might require data that can only

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be acquired through engine testing. For example, some dovetail coatings have special dimensional requirements to avoid overstressing interfacing critical parts. In cases like these, it is not appropriate to rely on assumed product effects from dimensional differences or assume applicability of ICA across product models within a product family.

**p. Test Parts.**

(1) Parts that conform to the replacement part drawing are considered eligible for certification testing. Parts that do not conform to the replacement part drawing must be reconciled to show the nonconforming feature will not affect the property being assessed by the test.

(2) If validation testing shows there are performance differences between the type design part and the replacement part that could be attributable to geometric differences, the replacement part manufacturer should verify that the dimensional characteristics of their replacement part meet their drawing requirements. The manufacturer should also verify that the drawing requirements contain all the dimensional attributes that maintain functional similarity to the type design part.

(3) If the applicant finds the dimensional attributes of the tested replacement parts to be nonconforming, the applicant should reassess their manufacturing capability. The applicant should conduct an evaluation to determine if the nonconformities are responsible for the test result shortfalls or part failures. Section 21.137 (referenced by 21.307), paragraph (i), requires procedures for implementing corrective and preventive actions to eliminate the causes of an actual or potential nonconformity to the approved design.

(4) If the applicant finds the dimensional attributes of the tested replacement parts conform to the drawing and no other cause for the performance difference is identified, the reverse engineering process used to develop the dimensional characteristics of the replacement part should be reexamined for potential sources of variation in features that could have influenced the outcome of the test.

**q. Dimensional Development.**

(1) The FAA's procedures for replacement parts allow applicants to provide a compliance showing using data from part-to-part comparative tests. Applicants must have sufficient resources to develop accurate dimensional data from the type design parts they elect to copy and repair. Sufficient resources will obviate the need for a product test to show the product continues to meet its airworthiness requirements when it is configured with the replacement part.

(2) Sufficient resources also presumes that you, the applicant, reverse engineer the replacement parts to be within the measurements taken from type design parts, using suitable methods, and that you dimension your replacement parts using dimensioning practices that are consistent with those used by the TC holder. It also presumes the testing and computing methods you used are capable of detecting differences, and assessing the effects of dimensional differences on product compliance.

(3) Since a replacement part manufacturer does not have access to all the information they need to fully replicate the type design part, there is a potential for differences to exist in replacement parts. Consequently, applicants must have demonstrated knowledge of the product sensitivities to dimensional differences in the specific replacement part they are making to show it does not have differences, or that any potential difference will not affect product compliance. The applicants usually demonstrate the extent of their product knowledge in their safety analysis.

(4) Methods used for dimensioning that are based on statistical techniques, similarity in manufacturing processes, similarity to other parts, or similarity in installations to develop or validate a part's dimensional characteristics will not meet our expectations for replacement parts or non-type design repairs. These techniques can mask the presence of physical and functional differences. Differences can result in improper function of the replacement part and affect product compliance by varying degrees, depending on the criticality of the part.

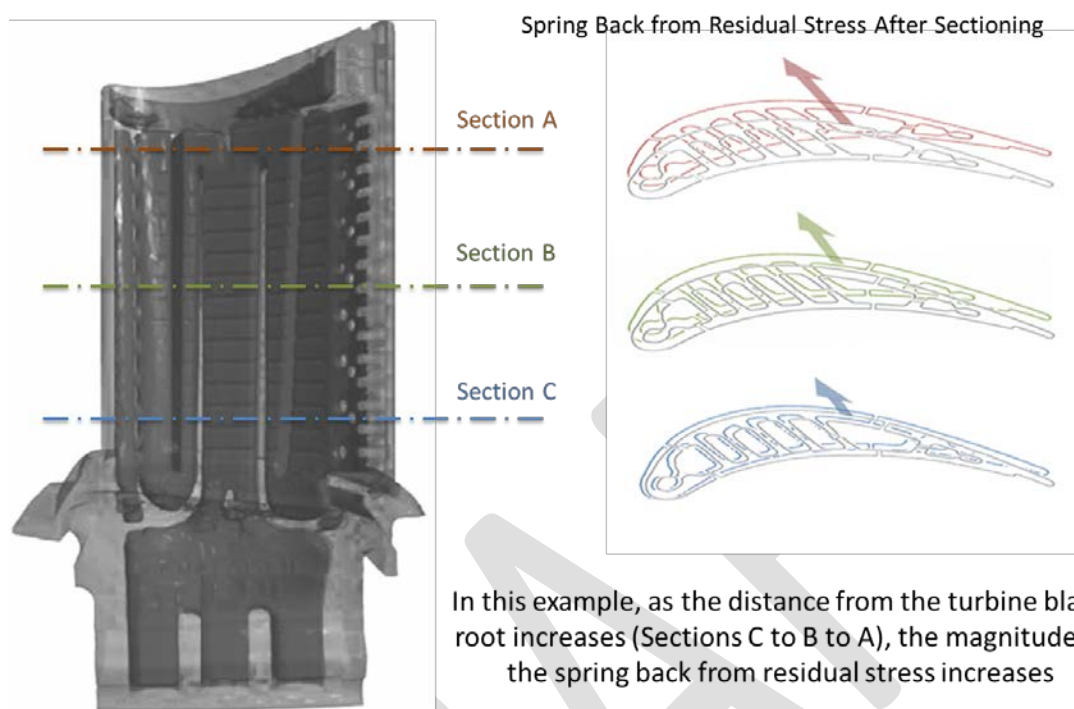
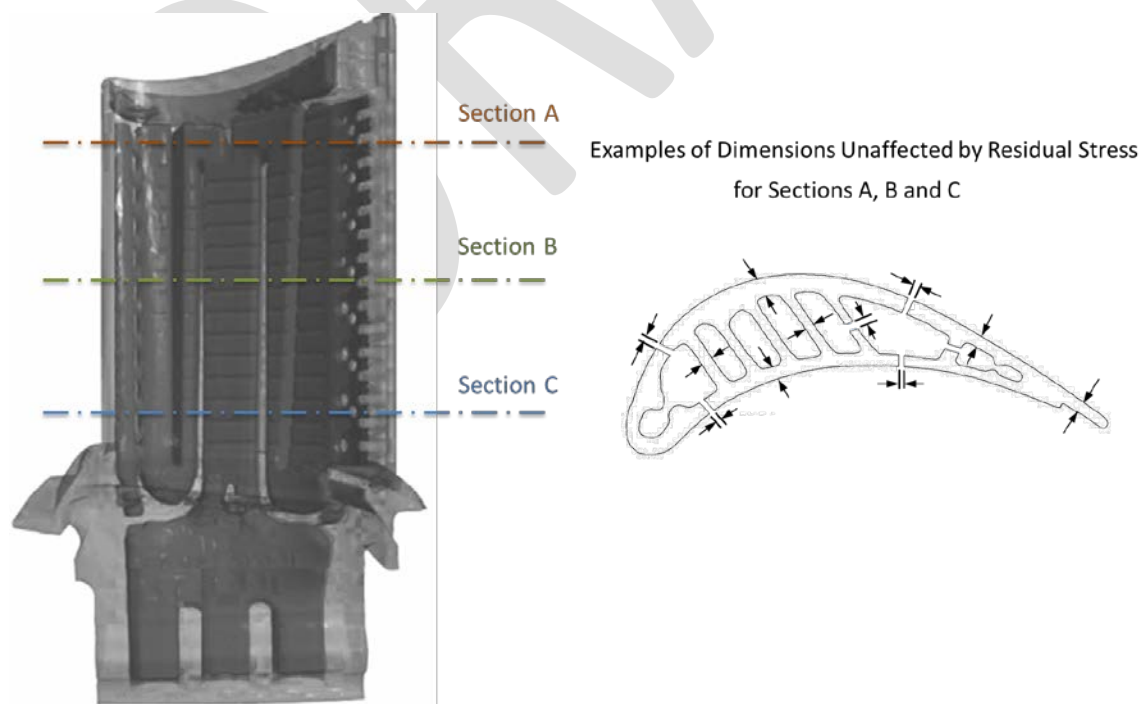
(5) If the potential effects of product dimensional differences in the replacement part are substantial enough to warrant a re-evaluation of product compliance to the applicable regulations, a re-evaluation of the engine manufacture's ICA is also required to determine if supplemental ICA are needed. Depending on the potential product effects, the data for this re-evaluation might only be available through product testing or compliance methods comparable to an STC.

**r. Destructive Methods.**

(1) Some engine parts have internal cavities and labyrinth passageways that allow cooling air to pass through the core of the part to remove heat from external surfaces exposed to hot gas temperatures. These internal features allow a thermal balance in the part that inhibits deterioration from certain thermally induced failure modes, such as heat induced cracks and creep. The manufacturing techniques used to create internal features can involve processes, such as casting, which often result in residual stresses.

(2) When applicants use destructive methods to quantify the dimensional characteristics of internal features in parts that have residual stresses, the resulting geometry of the sectioned part could be inaccurate. There could be a tendency for the part to shift, or spring back, when residual stress is relieved as the part is progressively sectioned for the dimensional analysis. When this occurs, the resulting measurements will be inaccurate.

(3) If applicants use destructive methods to reverse engineer a type design part, ensure that the parameters being acquired are not affected by geometric shifts that occur from residual stress. Figure 13 shows an example of surfaces that can shift from residual stress during a destructive evaluation. Figure 14 shows where dimensional properties are independent of the physical distortion that occurs when the residual stress is relieved.

**Figure 13. Effects of Residual Stress from Destructive Evaluation****Figure 14. Features Independent of Residual Stress during Destructive Evaluation**

**s. Dimensional Validation.**

(1) The compliance requirement of a replacement part is to show that the affected product continues to comply with its airworthiness requirements when it is equipped with the replacement part that is manufactured to the extent of its dimensional limits. Showing dimensional similarity is very dependent on how the replacement parts and the type design parts are dimensioned. Since type design dimensioning details are not available to the replacement part manufacturer, there is a potential for missing criteria, or introducing new criteria, that increases the dimensional variation in replacement parts beyond the extent intended by the original part designers.

(2) The sample of replacement parts used for compliance testing will not likely represent the full range of dimensional variation in the reverse engineered design. Therefore, functional test results could be misleading if the dimensional variations in the replacement parts represent a small range, or a bias, within the full tolerance band, and the product compliance is sensitive to the effects of dimensional variation. The conformity data should show if the sample replacement parts being tested have any dimensional characteristics that could limit the applicability of the compliance test results to the specific samples being tested and not to production parts that represent typical process variation.

(3) The applicant should check the sample population of replacement parts being tested for characteristics that could invalidate the compliance test results for parts manufactured to the dimensional extremes of the reverse engineered design, which includes the cumulative effect of differences in nominal shape and tolerance. Due to the potential for dimensional differences to exist in replacement parts, the effects of some features on important properties, such as the center-of-mass, contact stresses, and interfaces with critical parts could be substantial. For reverse engineered designs that exhibit dimensional differences, applicants may be able to use an analysis calibrated to the data acquired from the certification test samples to further assess the part at the dimensional extremes of the reverse engineered design to complete showing of functional similarity. We discuss several potential sources of dimensional variation in this AC.

(4) If the compliance plan was developed assuming the assessments would show dimensional similarity, but the results demonstrate there are differences in the replacement part, the compliance plan will either need to be expanded to consider the effects of the differences on product compliance, or the design will need to be changed to replicate the functional performance of the type design part in order to complete the dimensional validation process. This might require additional specimens and tests in a higher level assembly using a range of boundary conditions. Although not covered in this AC, differences resulting from the replacement part manufacturing processes and materials should also be resolved in a similar manner.

**t. ICA Maintenance Manuals.**

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(1) TC holders develop ICAs (i.e. maintenance manuals) for type design parts installed on their products. The manual serviceability and return-to-service instructions assume the engine configurations are being managed throughout their lifecycle using TC holder parts and maintenance practices. The manual tests, inspections, and limits account for aspects of the type design that might have changed since it was new, and those aspects that continue to conform to the type design drawing requirements. Therefore, TC holder maintenance manuals do not check all the dimensional characteristics that are important to the design, nor do they implement tests and inspections that will account for differences that might be introduced to a replacement part by reverse engineering.

(2) Replacement part designs based solely on the information available in OEM maintenance manuals have resulted in unsubstantiated differences in new replacement parts and repairs, and differences in the way replacement parts deteriorate when in service. Therefore, procedures in the TC holder maintenance manuals alone do not provide sufficient information to develop or validate reverse engineered designs or repairs. Because of this, maintenance manuals are not applicable to the replacement part until after the replacement part has been found to be equal to the type design part in terms of form, fit, and function.

(3) Applicants must use the test procedures in maintenance manuals appropriately. For example, some airflow tests conducted as part of a repair are only intended to check for damage or blockage that might have occurred during the repair process. Although the results might suggest that replacement parts and type design parts have similar cooling characteristics, it is not likely the tests will provide any insight to how the parts compare in an engine environment. Also, these tests will not reveal which features on the part could be significant to product compliance. The test will only show how air flows through the parts when they are tested under similar bench conditions.

(4) If there are dimensional differences in the replacement part and the part operates in a dynamic environment at elevated temperatures and pressures, the effects of dimensional differences on product compliance might only be observable while the part is functioning in the operating environment, or by analytical means that are grounded in engine data. Depending on the specific part and the related engine sensitivities, the effects of dimensional differences could result in invalidating the TC holder's ICA, such as the mandatory replacement times for life-limited parts. Some engine manuals provide a list of parts that have a substantial influence on life-limited parts. These parts require reverse engineering and design validation techniques that are commensurate with the complexity of the type design part, the parts they influence, and the engine system in which they operate.

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If you have comments or recommendations for improving this AC, or suggestions for new items or subjects to be added, or if you find an error, you may let us know about it by using this page as a template and 1) emailing it to 9-AWA-AVS-AIR500-Coord@faa.gov, or 2) faxing it to the attention of the AIR Directives Management Officer at 202-267-3983.

Subject: (insert AC number and title)

Date: (insert date)

Comment/Recommendation/Error: (Please fill out all that apply)

An error has been noted:

Paragraph \_\_\_\_\_

Page \_\_\_\_\_

Type of error (check all that apply): Editorial\_\_\_\_ Procedural\_\_\_\_ Conceptual\_\_\_\_

Description/Comments: \_\_\_\_\_

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Recommend paragraph \_\_\_\_\_ on page \_\_\_\_\_ be changed as follows:  
(attach separate sheets if necessary)

\_\_\_\_\_

In a future change to this AC, please include coverage on the following subject:  
(briefly describe what you want added attaching separate sheets if necessary)

\_\_\_\_\_

Name: \_\_\_\_\_